DETERMINATION OF MARINE WEATHER EXTREMES

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Abstract

Materiel should withstand the rigors of the weather and climate. A greater cost usually is required when the materiel must withstand weather for a longer period of time or withstand a greater extreme.

The cost to produce materiel for all weather extremes is great. The cost is great even when only two or three weather elements are considered. The U. S. Navy, Air Force and Army recognize the problem and have issued the Military Standards (MIL-STD) 210A to help solve the problem. However, the use of MIL-STD 210A to establish specifications for materiel based on low probabilities of failure and independence of weather events may result in over specification which requires waivers, increased time and increased costs.

This paper presents some of the information for marine areas which will allow better specifications based on more new data, a less restrictive specification for failure and for dependence of weather events. Graphical presentation is for the .01 probability. Specification of failure levels at .05 or .10 may be more reasonable in the light of weather dependence.

Not all features of weather extremes of the atmosphere and ocean are considered here. Neither are the simultaneous occurrences of weather events used.

Introduction

One of the more fascinating aspects of our environment is the extreme behavior of the atmosphere and sea. There are many types of extremes - the world's record for a single type of observation, record durations, monthly or seasonal extremes, and mammoth storms, to name a few. "Record" is the key word. All actual (as opposed to theoretical) extremes must be recorded to be known. This requires an observation to be taken at the exact time and place that an actual extreme is occurring. Observing practices make this requirement almost impossible to fulfill. The recorded extremes, therefore, are considered to be only estimates of the actual extreme environmental conditions.

The rare occurrences of an event may provide interesting reading, but they also have practical applications. Engineers and architects design equipment to withstand certain environmental conditions. Economically, it is not feasible to design equipment that will withstand all extremes. The user must assume a risk. He must be willing to accept the consequences of a piece of equipment failing, say, once in fifty years. For this reason, extremes that are used for design criteria are generally treated probabilistically. The record of observations is used to determine the likelihood of obtaining reasonable weather extremes in any given length of time.

The probabilistic approach to marine environmental extremes presented in this paper is extracted from a working document prepared for the revision of Military Standards (MIL-STD) 210A to 210B, Climatic Extremes for Military Equipment. The working document was written at the National Climatic Center, Environmental Data Service, National Oceanic and Atmospheric Administration, Asheville, N. C. It was used by the Commander, Naval Weather Service Command, Washington, D.C., as the U. S. Navy input to the revision of MIL-STD 210A. Land extremes were prepared by the U. S. Army and upper air extremes by the U. S. Air Force.

The military standards are for the weather or climatic extremes used to prepare manufacturing specifications for materiel. At times, present specifications may not be used judiciously. For example, a piece of electronic gear may be required to pass tests of extreme temperature simultaneously with extreme relative humidities in the test chamber. In nature the highest temperatures in the open do not occur with the highest relative humidities. In addition, the probability level may be too restrictive. Both of these factors increase the production costs beyond all reason for the equipment will never encounter such open air conditions.

Simultaneous occurrences of several weather elements at a time would provide a better basis for specification preparation. However, such studies are often difficult to make. Therefore, these studies, where simultaneous conditions are required, are limited to only the one percent level for a particular element. Diurnal curves are then prepared for the accompanying elements for those times when the primary element exceeds the one percent level.

Open air situations are the basis for this study. Conditions within enclosed spaces, such as caves, underground storage, below decks, or in buildings are not a part of this presentation. This study excludes also Antarctic data of all types.

This paper contains only a part of the information to be included in the revision of Military Standards 210A. All information in the revision will be presented in tabular form. No curves or functional representation will be made. However, in the working paper additional data and forms of presentation are included. The four empirical probability levels of extreme conditions, 0.20, 0.10, 0.05 and 0.01, were selected. The 0.01 level will be the major level. The values for the 0.01 probability levels will be shown below. In addition, wherever possible, an average diurnal curve will be shown for all days on which the 0.01 empirical probability level was equaled or exceeded in the extreme sense. For example, for low conditions, such as low temperatures, this is understood to be occurrences of temperatures below a stated criterion.

No actual bivariate or multivariate conditions are to be shown. These and other considerations may be investigated and given in subsequent sub-revisions of MIL-STD 210B.

Information Presentation

The evolution of discussion, development and agreement as to what would be included in the revision of MIL-STD 210A to 210B is not enjoined here. Rather it is more pertinent to give some idea as to just how the information is to be presented. For purpose of reference a world map, showing the numbering of Marsden Squares, is presented in Chart 1. Near the equator these areas are essentially square. As the areas approach the polar regions they take on a rectangular appearance in a global presentation.

Data Source

Marine data are stored, generally, in the archives by Marsden Square. All surface atmospheric data referred to in the text as being for a Marsden Square were taken from the common Marine Format TDF-11 (Tape Data Family) on file at the National Climatic Center, Asheville, N. C. Instruments are located at different heights on different ships and it is impossible to tell from the data at which height above the sea surface they were taken. The assumption was made, therefore, that all instruments were at the same height, and the data were used as if they were homogeneous. Radiosonde data on file at the National Climatic Center provided the basis for upper air marine environment extreme profiles of temperature.

Data Presentation

I. Ocean Wave Heights and Spectra

The mean height of the highest third of all waves present in a wave train, called the significant wave height and often designated as ($\overline{H}_{1/3}$), and the extreme wave heights are important in the design of ships. Figure 1 provides an estimate of the average significant wave heights during wave build-up with increasing wind speeds and during wave decay with decreasing wind speeds. This figure is based on a study by Vaiksnoras and Crutcher as revised by Crutcher [1] and assumes optimum fetch and duration conditions. Tabular information is presented in Table 1. The observed data, as shown by the heavy solid curve in the figure, indicate that as the wind speed decreases, the waves will decay slower than they built up.

The extreme wave height is empirically estimated to be 1.8 times the significant wave height. Thom [2] applied the Fréchet extreme-value distribution to extreme wave heights. He fitted annual extreme significant wave height data by the Fréchet distribution and then adjusted the distribution to extreme wave heights by applying the scale transformation. His results are depicted graphically in Figure 2 and in tabular form in Table 2. The data show that 50 percent of the years could have wave heights in excess of about 72 feet and 5 percent of the years could have waves in excess of 116 feet.

For a detailed discussion of the effect of swell and wave action on ships and the frequency responses of ships please see Lewis [3].

II. Maximum Temperatures

The highest air temperatures encountered by mariners may be expected to occur in ports. The U. S. Navy [4] has recently published monthly average temperatures for the Northern Hemisphere. These data were screened along with those furnished by the U. S. Air Force and published by the U. S. Navy [5] to select the area with the highest temperatures. The port selected was Abadan, Iran. The data for Abadan were tabulated from highest to lowest and cumulative frequencies were computed. The expected diurnal range of temperatures corresponding to a maximum temperature equal to the computed 99th percentile value is plotted on Figure 3 and tabulated in Table 3. Corresponding diurnal ranges of relative humidity and insolation also are presented.

Figure 4 and Table 4 present the same type of information for the air temperature over the sea based on data screened from the U. S. Navy [6, Vols. II, VIII]. The extremes are found in the Persian Gulf and Gulf of Oman. Since this area is rather confined by land, maximum temperatures over the open ocean also were examined. The diurnal range for temperature and corresponding relative humidity and insolation for the warmest open ocean area - Marsden Squares 019 and 055 - are depicted in Figure 5 and Table 5.

A survey was made of U. S. Navy [6, Vols. III, VIII, 7] for areas of maximum sea surface temperatures. The extremes occurred in the Persian Gulf. The diurnal range of the maximum sea surface temperatures and corresponding air temperature, relative humidity and insolation is shown on Figure 6 and Table 6. These ranges were inferred from hourly means of data taken from those days on which the 99th percentile value of sea temperatures was exceeded and from the work of Svedrup et al. [8], Kuhlbrodt and Reger [9], and Krummel [10].

III. Relative Humidity

Areas of high relative humidity can occur both in cold and warm climates. For a given relative humidity, more moisture is present at a warm temperature than at a cold temperature. Warm areas of high relative humidity were therefore investigated, although it may be necessary to investigate cold areas at a later date.

Because of drying considerations, it was felt that low relative humidity in conjunction with high temperatures would be more significant than low relative humidity in conjunction with low temperatures. It may be necessary, however, to investigate the latter case at a later date.

U. S. Department of Agriculture [11] was studied to determine areas of small and large wet bulb depressions in order to find warm areas of high and low relative humidity. Based on the availability and quality of data, Marsden Squares 322 and 372 were chosen to be most representative of the high and low open ocean relative humidity cases, respectively. Diurnal ranges of the relative humidity with corresponding ranges of air temperature and insolation are presented in Figure 7 and Table 7 for high relative humidity and in Figure 8 and Table 8 for low relative humidity.

IV. Temperatures, Withstanding

The port of Abadan and open ocean Marsden Square 103 were chosen for maximum withstanding air temperatures. The annual maximum temperatures for each location were plotted on semi-logarithmic normal probability paper and a confidence envelope was plotted according to a procedure developed by Gringorten [12]. The median line for a normal distribution with the same mean and standard deviation as the yearly extreme sample was drawn to represent a line of best fit. From this line it is possible to pick the maximum design temperature for any withstanding period up to 1000 years. Figure 9 shows the curves for the port and open ocean. Tabular data are shown in Table 9. Techniques for converting the graphical data to the tabular data are given by Air Force Cambridge Research Laboratories [13].

Minimum air temperatures were treated in a similar fashion. Barrow, Alaska, was chosen as the coldest port primarily because it has a long period of record available and because it appears to be at least as cold as any of the other stations investigated. In addition, the temperature extremes for Anchorage, Alaska, a port open all winter, were analyzed to provide a contrast with Barrow which is closed by ice in the winter. Ocean Station Bravo provided the data for the open ocean. The withstanding curves for minimum air temperature are presented in Figure 10, and tabular data are included in Table 9.

Maximum and minimum sea temperatures also were examined in like manner. U. S. Navy [6, Vols. III, VIII] data showed that maximum sea temperatures occur in the Persian Gulf and minimum sea temperatures occur off the coast of Newfoundland, Canada. A graphical presentation of the withstanding curves is found in Figure 11, while tabular data are found in Table 10.

Deep sea bottom water temperatures hover around 4°C because of the physical characteristics of water. Water has a maximum density near that temperature.

V. Wind Speed

It was felt that a tabulation of peak gusts coupled with a study of durations of sustained wind speeds would best describe the wind extremes.

Using the same procedure as for temperatures, withstanding criteria for peak gusts were developed for ports and the open ocean. Gusts associated with typhoon and hurricane conditions were not included. Adak, Alaska, was chosen as the windiest port and Ocean Station Delta as the windiest open ocean location. The withstanding curves are depicted in Figure 12 with corresponding data listed in Table 11.

Withstanding conditions for typhoon conditions are shown in Figure 13 and Table 11. The data came from a listing of maximum typhoon winds for the years 1953-1967 prepared by the Naval Weather Research Facility, Norfolk, Virginia, and from work done at the National Climatic Center, Asheville, North Carolina, on maximum recorded winds during the years 1945-1952.

The original recorded winds at Adak were analyzed to determine wind speed durations at ports. The time of duration for winds above 34 kt, between 50-59 kt, 60-69 kt, 70-79 kt, and above 80 kt was noted. Each of these groups then was listed in descending order of length of duration of the sustained wind and empirical probability levels of occurrence were determined. For the open ocean, the duration of each occurrence of gale force winds (above 34 kt) was noted for Ocean Station Bravo. Ships are not required to document the duration of any winds except gales. Empirical probability levels of occurrence of specified durations then were determined. Table 12 presents the wind duration data.

VI. Minimum Temperature Duration

Several ports in cold areas were investigated for temperature record. Because of the requirement for a long period of hourly temperature data, the search was narrowed to U. S. first order stations. Two stations were chosen: Barrow, which is closed to normal sea traffic by ice during part of the year, and Anchorage, which is open to sea traffic during all months of the year. A survey of Ocean Station Vessels revealed that Bravo is in the coldest area and thus was chosen as representative of the open ocean.

A computer program was prepared to search the data records and to count the number of hours that a temperature remained at or below a given value. A listing was produced which presents a count of occurrences of each temperature for each duration interval from 1-144 hours.

Cases where the duration of a given temperature lasted longer than a three-month period in any one year were not counted in the final listing but note was made of these occurrences. A list was prepared of the temperatures associated with each duration and four empirical probability levels were picked. These four temperatures for each duration interval then were standardized by

$$t_m = \frac{t - \bar{t}_{min}}{\bar{R}_m}$$

where t is the temperature in degrees F, $\bar{t}_{min}$ is the average monthly minimum temperature, R_m is the average monthly temperature range, and t_m is the standardized value. The procedure is given by Sharon [14].

The standardized temperature values were plotted versus duration in hours and a smooth curve drawn through the points for each empirical probability level. Standardized values then were picked from the curves and transformed to temperature values by re-arranging the above equation.

Values for open and closed port and open ocean minimum air temperatures are given in Tables 13, 14, and 15, respectively, and plots are shown in Figures 14, 15, and 16, respectively. The duration of minimum sea temperatures is given in Table 16 and Figure 17. Future work and expansion of this study undoubtedly will show a further smoothing of the lines and establishment of better symmetry.

VII. Visibility

Marine visibility observations are subject to more sources of error than those taken on land. Ships that have sailed out of sight of land have no point of reference from which to judge visible ranges. In addition, reported low visibilities at night sometime result from darkness rather than an obstruction to vision.

Notwithstanding the observing problems, two areas over the oceans stand out as having low visibilities - the area around the South Sandwich Islands and the area just south of the Kamchatka Peninsula. The latter area is worse. During June, the warm, moist air comes in contact with cold water to form heavy fog. The records indicate that in this month, 82.7 percent of the visibilities are less than 1/4 nautical mile, 85.3 percent are less than 1 mile, and 93.6 percent are less than 5 miles.

VIII. Salinity

Salinity affects buoyancy, the freezing temperature of the water, and air-sea interactions, all of which play an important role in the maritime climate. The variability of salinity over the ocean has not been determined to the extent that the distribution of extremes is known. Jacobs [15] shows salinities over the North Pacific and North Atlantic Oceans of greater than 36 °/oo and 37 °/oo, respectively. Sverdrup [16] indicates average maximum salinities of about 41 °/oo in the Red and Arabian Seas. Values as high as 45 °/oo have been measured. Low salinities of less than 1 °/oo are fairly common near estuaries, snowmelts, glaciers, and in places like the Gulf of Bothnia.

IX. Upper Air Temperatures

Upper air environmental temperature extremes over navigable waters and ports are presented in Figure 18 and Table 17. Low and high extremes are given in heights above sea level up to 16 km. Above this level the atmospheric profiles are coincident with the world-wide upper air extremes prepared by the U. S. Air Force. The profiles presented do not represent dynamic internal consistency of the atmosphere. They are simply envelopes of extreme conditions.

The data for the extreme profiles for naval operations came primarily from the U. S. Navy [4, 17]. The profiles were developed from monthly mean values and standard deviations of atmospheric parameters at specified altitudes. The risk values were determined by using a statistical approach coupled with empirical data. An attempt was made to make the extreme profiles realistic in view of naval operations.

The highest temperatures generally occur in the Northern Hemisphere summer. Up to about 12 km, these high temperatures are found over the Arabian Sea. Above this level the extreme high temperatures are found near the Aleutian Islands. The lowest temperatures are found during winter. Up to about 8 km, they occur over the North Atlantic Ocean off the coast of Labrador. Above 8 km, the coldest temperatures are found over the waters circling Antarctica. It should be noted that the worldwide navigable waters stretched from 60°N to 60°S. It was felt that poleward of these boundaries surface naval operations essentially would cease because of sea ice, extremely cold temperatures, or other harsh environmental factors.

Summary

The determination of extreme conditions in the maritime environment has been undertaken to establish design criteria for materiel involved in worldwide naval operations. An attempt was made to provide logical and realistic estimates of the extremes for the sphere of naval activities. As knowledge of the climate increases through the collection of more data and through more sophisticated analytical techniques, better and more precise estimates of the extremes can be obtained.

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TABLE 1. WAVE HEIGHT (FT) FOR INCREASING AND DECREASING WIND SPEED

	Wind Speed (kts)											
	10	20	30	40	50	60	70	80	90	100	110	120
Increasing Wind Speed	2.0	5.5	12.5	22.0	33.0	45.5	59.5	72.0	85.5	96.0	105.0	107.5
Decreasing Wind Speed	5.0	12.0	24.0	37.5	51.0	64.0	82.0	87.5	96.0	101.0	102.0	107.5

TABLE 2. QUANTILES - EXTREME WAVE HEIGHTS (FEET) $[(\overline{H}1/3)x(1.8)]$ (AFTER H.C.S. THOM, 1971)

Probability Level	0.50	0.20	0.10	0.05	0.04	0.02	0.01
Wave Height (ft.)	72	88	101	115	120	137	156

TABLE 3. DIURNAL VARIATION, PORT MAXIMUM AIR TEMPERATURE, PROBABILITY LEVEL 0.01

Maximum Air Temperature °F 118.0
°C 47.8

	Hour Local Mean Time											
Element	01	03	05	07	09	11	13	15	17	19	21	23
Air Temperature °F	90.8	87.3	84.6	86.3	99.8	110.1	116.0	118.5	115.4	106.9	99.3	94.7
°C	32.7	30.7	29.2	30.2	37.7	43.3	46.7	48.1	46.3	41.6	37.4	34.8
Relative Humidity %	50.7	55.3	64.2	60.9	37.5	27.9	22.1	21.1	26.9	37.2	43.3	47.2
Insolation Ly/Hr	00	00	00	36	73	92	92	70	33	01	00	00

TABLE 4. DIURNAL VARIATION, SEA SURFACE MAXIMUM AIR TEMPERATURE, PROBABILITY LEVEL 0.01

Maximum Air Temperature °F 99.8
°C 37.7

	Hour Local Mean Time											
Element	01	03	05	07	09	11	13	15	17	19	21	23
Air Temperature °F	95.9	95.7	96.0	97.5	98.8	99.8	100.0	100.1	99.7	99.0	97.9	96.6
°C	35.5	35.4	35.6	36.4	37.1	37.7	37.8	37.8	37.6	37.2	36.6	35.9
Relative Humidity %	82.0	83.0	83.6	81.6	78.0	74.8	73.0	72.5	73.8	77.5	80.4	81.2
Insolation Ly/Hr	00	00	00	34	72	93	92	70	31	00	00	00

TABLE 5. DIURNAL VARIATION, OCEAN MAXIMUM AIR TEMPERATURE, PROBABILITY LEVEL 0.01

Maximum Air Temperature °F 92.0
°C 33.3

	Hour Local Mean Time											
Element	01	03	05	07	09	11	13	15	17	19	21	23
Air Temperature °F	84.3	84.0	84.0	84.8	87.6	90.2	91.6	91.5	90.5	88.5	86.4	84.6
°C	29.1	28.9	28.9	29.3	30.9	32.3	33.1	33.1	32.5	31.4	30.2	29.2
Relative Humidity %	84.7	84.9	84.7	84.0	80.7	76.4	74.1	73.9	75.0	79.4	84.2	84.8
Insolation Ly/Hr	00	00	01	24	66	86	86	64	28	00	00	00

TABLE 6. DIURNAL VARIATION, OCEAN MAXIMUM SEA TEMPERATURE, PROBABILITY LEVEL 0.01

Maximum Water Temperature °F 96.1
°C 35.6

Element		Hour Local Mean Time											
		01	03	05	07	09	11	13	15	17	19	21	23
Water Temperature	°F	92.9	92.6	92.9	93.7	94.8	95.5	95.9	96.1	95.9	95.4	94.6	93.5
	°C	33.8	33.7	33.8	34.3	34.9	35.3	35.5	35.6	35.5	35.2	34.8	34.2
Air Temperature	°F	92.5	92.5	92.8	94.3	95.8	96.7	96.9	96.9	96.4	95.6	94.3	93.0
	°C	33.6	33.6	33.8	34.6	35.4	35.9	36.1	36.1	35.8	35.3	34.6	33.9
Relative Humidity	%	84.3	85.6	86.0	85.6	84.3	82.7	81.3	80.0	78.8	78.0	78.8	81.4
Insolation	Ly/Hr	00	00	00	34	72	93	92	70	31	00	00	00

TABLE 7. DIURNAL VARIATION, OCEAN HIGH RELATIVE HUMIDITY, PROBABILITY LEVEL 0.01

Maximum Relative Humidity 100%

Element		Hour Local Mean Time											
		01	03	05	07	09	11	13	15	17	19	21	23
Relative Humidity	%	99.8	100	99.2	98.2	96.6	94.7	92.9	92.5	93.7	96.1	98.2	99.3
Air Temperature	°F	77.2	77.3	78.1	79.8	81.7	83.0	83.8	84.1	83.8	82.8	80.6	77.9
	°C	25.1	25.2	25.6	26.6	27.6	28.3	28.8	28.9	28.8	28.2	27.0	25.5
Insolation	Ly/Hr	00	00	00	19	59	83	83	63	23	00	00	00

TABLE 8. DIURNAL VARIATION, OCEAN LOW RELATIVE HUMIDITY, PROBABILITY LEVEL 0.01

Minimum Relative Humidity 55%

Element		Hour Local Mean Time											
		01	03	05	07	09	11	13	15	17	19	21	23
Relative Humidity	%	65.6	65.6	64.5	62.0	58.5	56.4	54.5	55.2	59.4	63.9	65.6	65.6
Air Temperature	°F	68.2	68.4	68.9	70.2	72.0	73.6	74.6	74.4	71.9	71.0	69.4	68.7
	°C	20.1	20.2	20.5	21.2	22.2	23.1	23.7	23.6	22.2	22.2	20.8	20.4
Insolation	Ly/Hr	00	00	00	33	74	96	98	82	44	00	00	00

TABLE 9. MAXIMUM AND MINIMUM AIR TEMPERATURE WITHSTANDING

Risk Level	Element	Location	Planned Life (years)							
			2		5		10		25	
			°F	°C	°F	°C	°F	°C	°F	°C
10%	Minimum Temperature	Closed Port	-55.5	-48.6	-57.5	-49.7	-58.9	-50.5	-60.5	-51.4
		Open Port	-34.1	-36.7	-36.9	-38.3	-38.7	-39.3	-40.9	-40.5
		Ocean	+ 3.7	-15.7	+ 1.6	-16.9	+ 0.5	-17.5	- 1.2	-18.4
10%	Maximum Temperature	Port	123.2	50.7	124.0	51.1	124.3	51.3	124.8	51.6
		Ocean	110.8	43.8	113.5	45.3	115.4	46.3	117.6	47.6

TABLE 10. MAXIMUM AND MINIMUM SEA TEMPERATURE WITHSTANDING

Risk Level	Element	Location	2 °F	2 °C	5 °F	5 °C	10 °F	10 °C	25 °F	25 °C
			Planned Life (years)							
10%	Maximum Sea Temperature	Ocean	99.1	37.3	100.0	37.8	100.8	38.2	101.5	38.6
10%	Minimum Sea Temperature	Ocean	~~21.7~~ 28.0	~~-5.7~~ -2.2	~~21.0~~ 28.0	~~-6.1~~ -2.2	~~20.5~~ 28.0	~~-6.4~~ -2.2	~~19.8~~ 28.0	~~-6.8~~ -2.2

TABLE 11. PEAK WIND - WITHSTANDING

Risk Level	Element	Location	2 kts	2 mps	5 kts	5 mps	10 kts	10 mps	25 kts	25 mps
			Planned Life (years)							
10%	Peak Wind									
		Port	101	52.0	111	57.1	118	60.7	124	63.8
		Ocean	109	56.1	118	60.7	125	64.3	134	69.0
		Typhoon	186	95.8	194	99.9	200	103.0	208	107.1

TABLE 12. MAXIMUM WIND SPEED DURATIONS

		Probability Level			
		0.20	0.10	0.05	0.01
Port	34 to 49 kts.	4 hrs.	7 hrs.	12 hrs.	18 hrs.
	50 to 59 kts.	2 min.	3 min.	7 min.	12 min.
	60 to 69 kts.	1 min.	2 min.	4 min.	10 min.
	70 to 79 kts.	1 min.	1 min.	2 min.	3 min.
	80 kts and above	1 min.	1 min.	1 min.	1 min.
Ocean	$\geq$ 34 kts.	6 hrs.	12 hrs.	24 hrs.	48 hrs.

TABLE 13. MINIMUM AIR TEMPERATURE VS DURATION (OPEN PORT), PROBABILITY LEVEL 0.01

	Duration (hours)									
	1	3	5	7	9	11	18	36	72	144
°F	-29.7	-28.7	-27.6	-26.7	-25.8	-24.8	-21.2	-14.8	- 9.7	- 7.3
°C	-34.2	-33.7	-33.1	-32.6	-32.1	-31.6	-29.6	-26.0	-23.2	-21.8

TABLE 14. MINIMUM AIR TEMPERATURE VS DURATION (CLOSED PORT), PROBABILITY LEVEL 0.01

	Duration (hours)									
	1	3	5	7	9	11	18	36	72	144
°F	-47.8	-47.4	-47.0	-46.6	-46.2	-45.8	-44.4	-41.2	-36.4	-31.0
°C	-44.3	-44.1	-43.9	-43.7	-43.4	-43.2	-42.4	-40.7	-38.0	-35.0

TABLE 15. MINIMUM AIR TEMPERATURE VS DURATION (OCEAN), PROBABILITY LEVEL 0.01

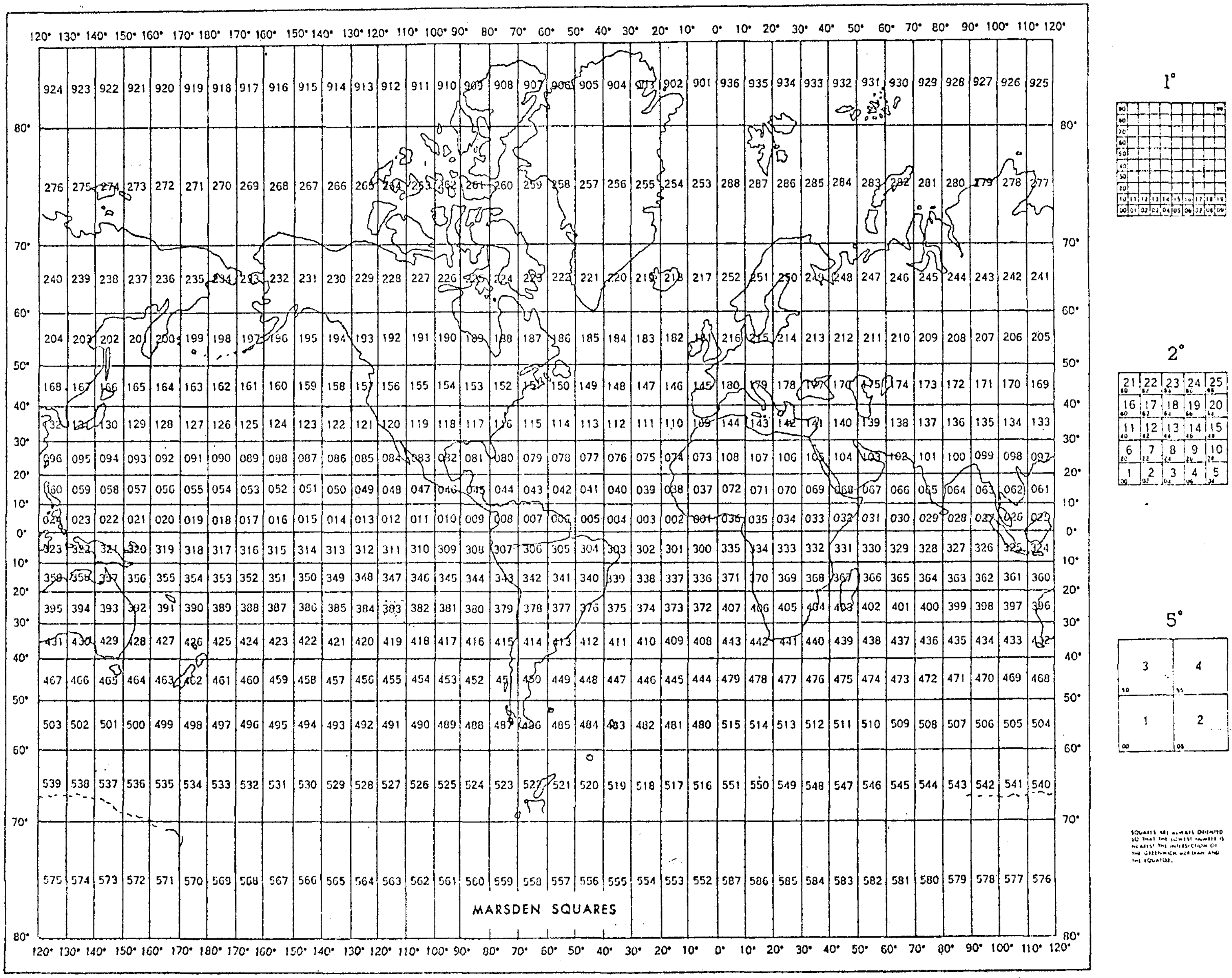
	Duration (hours)									
	1	3	5	7	9	11	18	36	72	144
°F	+ 7.2	+ 7.7	+ 8.2	+ 8.7	+ 9.1	+ 9.6	+11.3	+15.1	+20.4	+25.1
	-13.8	-13.5	-13.2	-12.9	-12.8	-12.4	-11.5	- 9.4	- 6.4	- 3.8

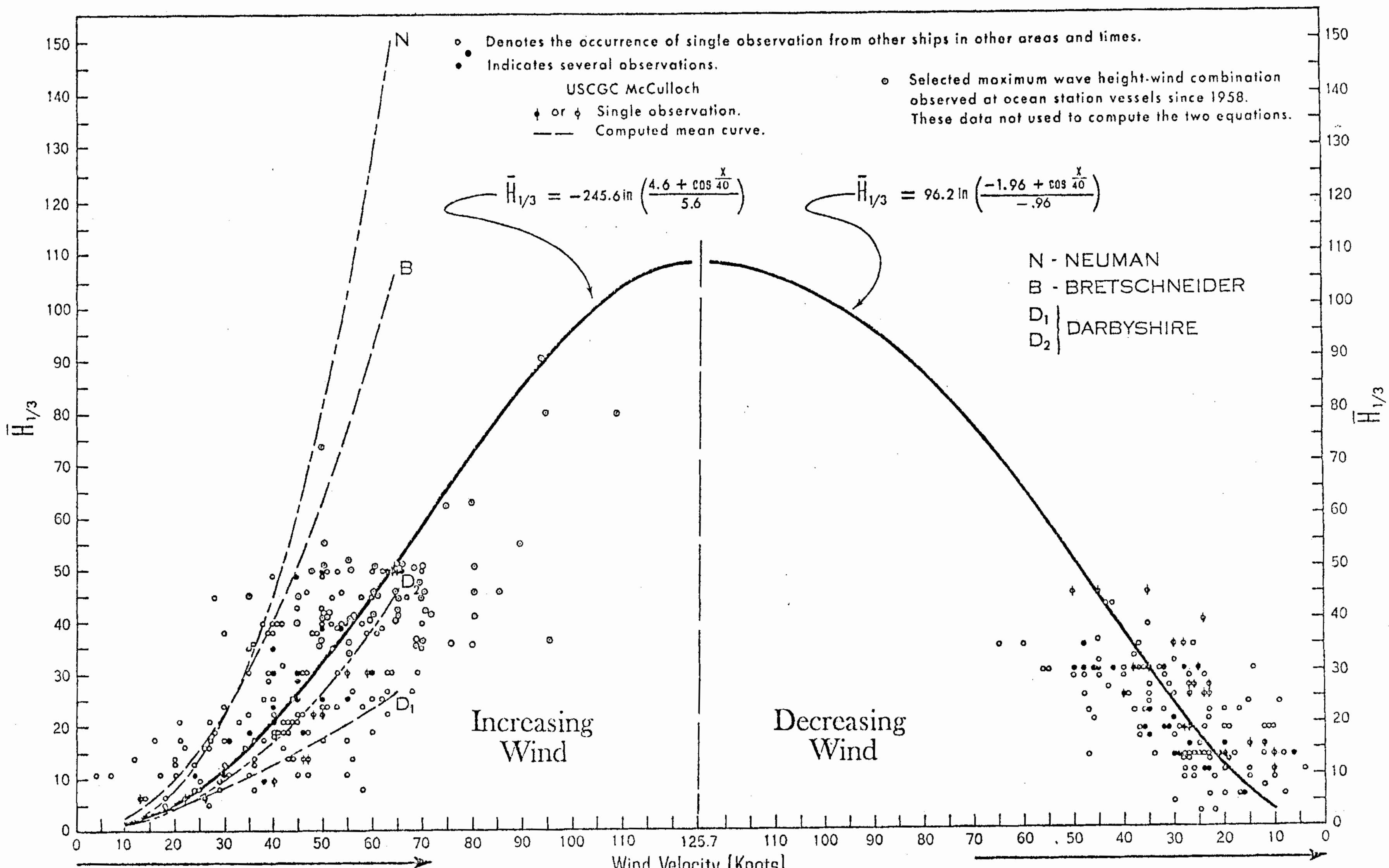
TABLE 16. MINIMUM SEA TEMPERATURE VS DURATION (OCEAN), PROBABILITY LEVEL 0.01

	Duration (hours)									
	1	3	5	7	9	11	18	36	72	144
°F	+28.2	+28.4	+28.6	+28.7	+28.8	+28.8	+29.1	+29.6	+30.1	+30.8
°C	- 2.1	- 2.0	- 1.9	- 1.8	- 1.8	- 1.8	- 1.6	- 1.3	- 1.1	- 0.7

TABLE 17. TEMPERATURE EXTREMES AT ALTITUDE, PROBABILITY LEVEL 0.01

		Altitude (km)									
		0	1	2	4	6	8	10	12	14	16
Maximum	°C	48	33	25	14	1	-9	-21	-39	-37	-37
	°F	118	91	77	57	34	16	- 6	-38	-35	-35
Minimum	°C	-34	-29	-31	-39	-46	-56	-69	-74	-75	-86
	°F	-29	-20	-24	-38	-51	-69	-92	-101	-103	-123


MARSDEN SQUARES
1°
2°
5°



$$\bar{H}_{1/3} = -245.6 \ln\left(\frac{4.6 + \cos\frac{x}{40}}{5.6}\right)$$

$$\bar{H}_{1/3} = 96.2 \ln\left(\frac{-1.96 + \cos\frac{x}{40}}{-.96}\right)$$

Figure I. Forecast Versus Visual Observed Wave Heights

(Adapted from Vaiksnoras and Crutcher 1960, Rev. 1969, unpublished)

MAXIMUM VALUE PROBABILITY FISHER-TIPPETT TYPE II

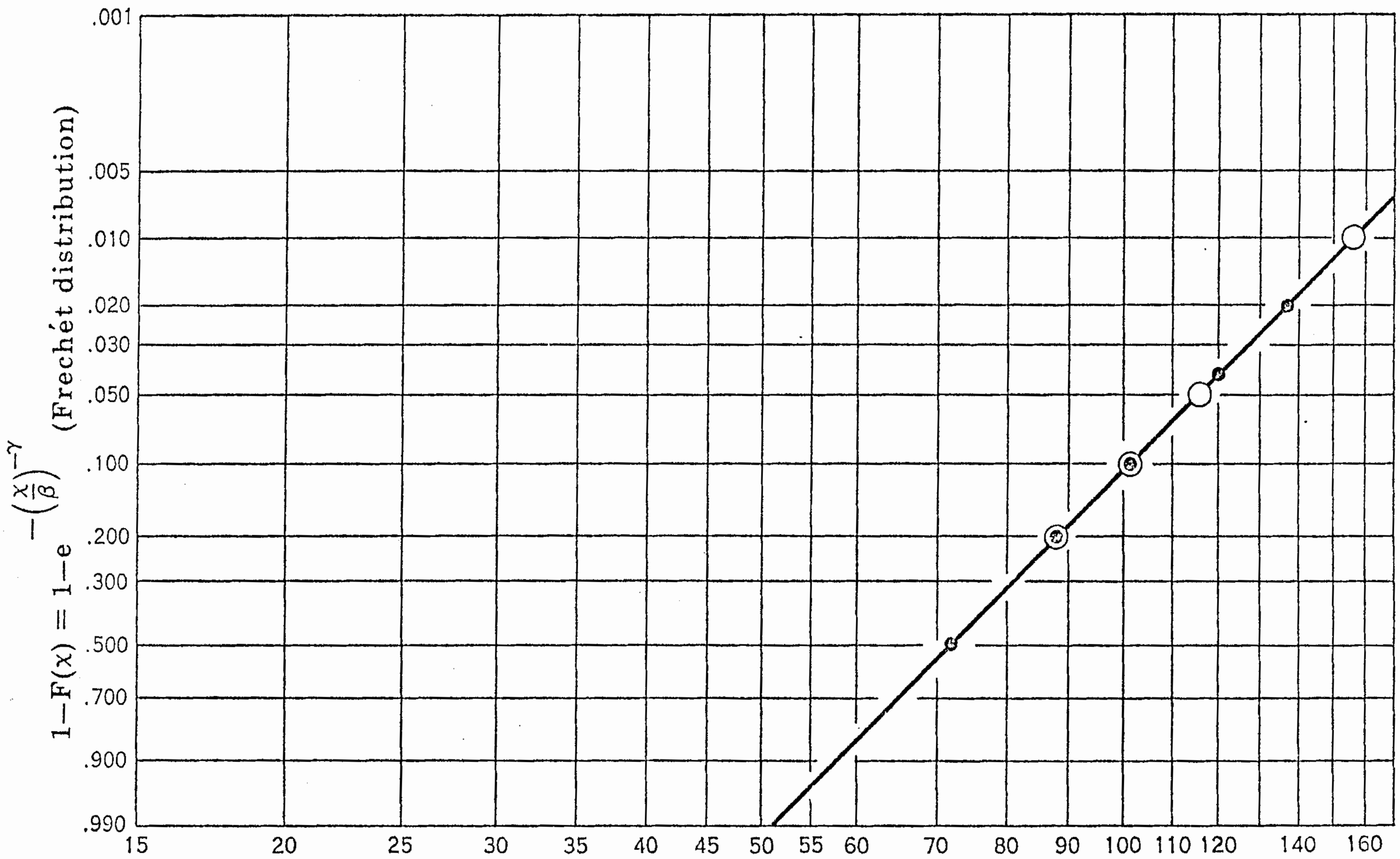
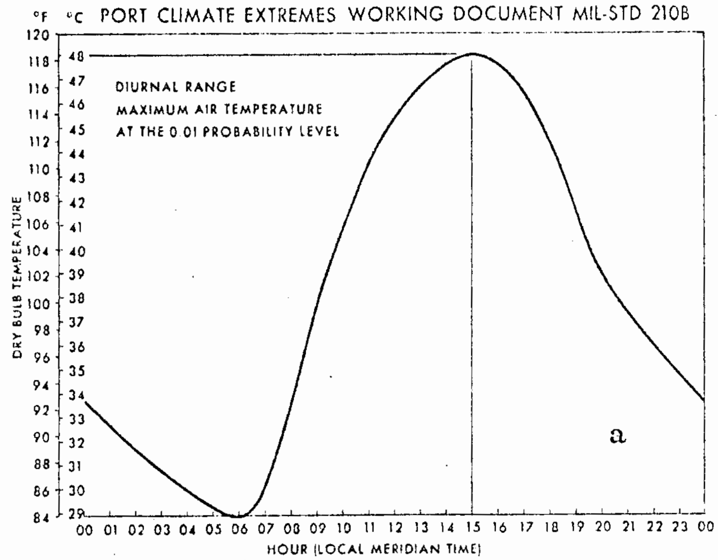
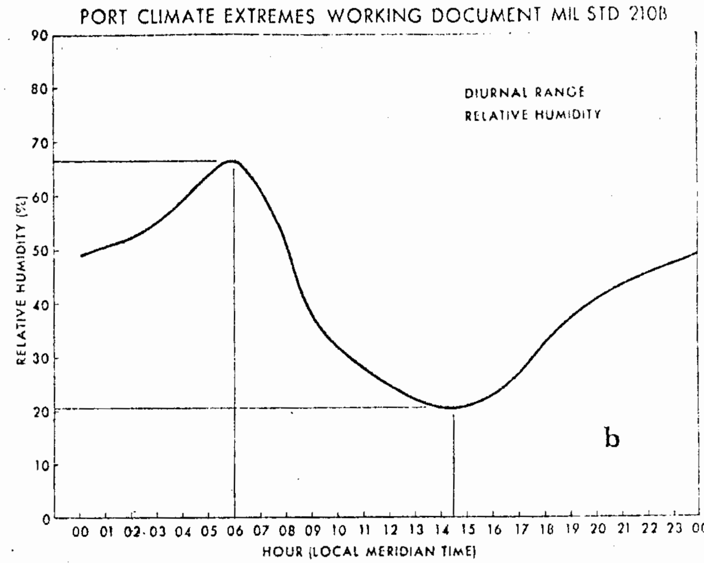
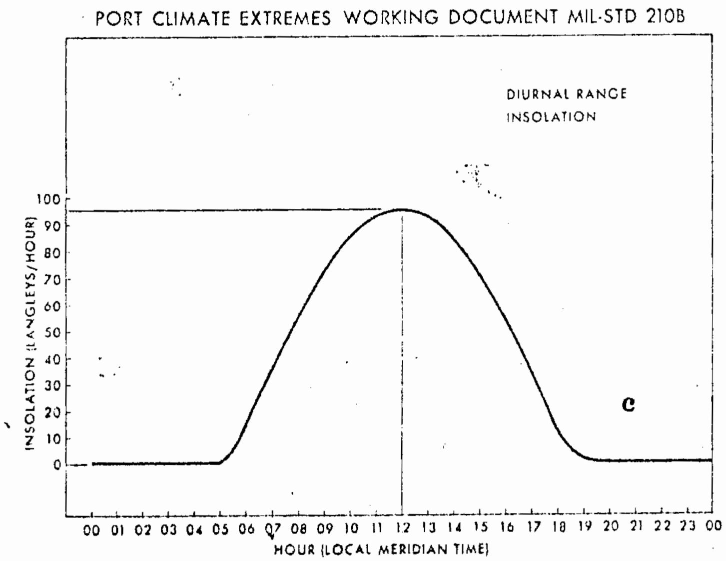


FIGURE 2. EXTREME WAVE HEIGHTS (Feet) [($\bar{H}$⅓)×(1.8) (after H.C.S. Thom, to be published)].



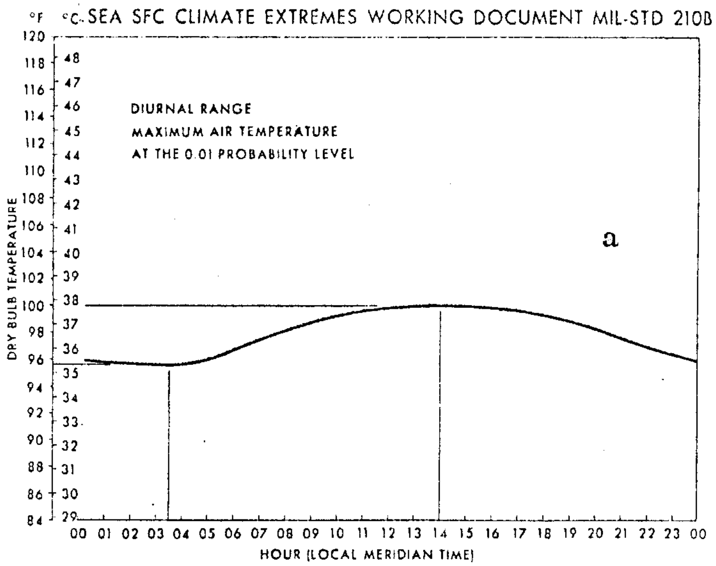


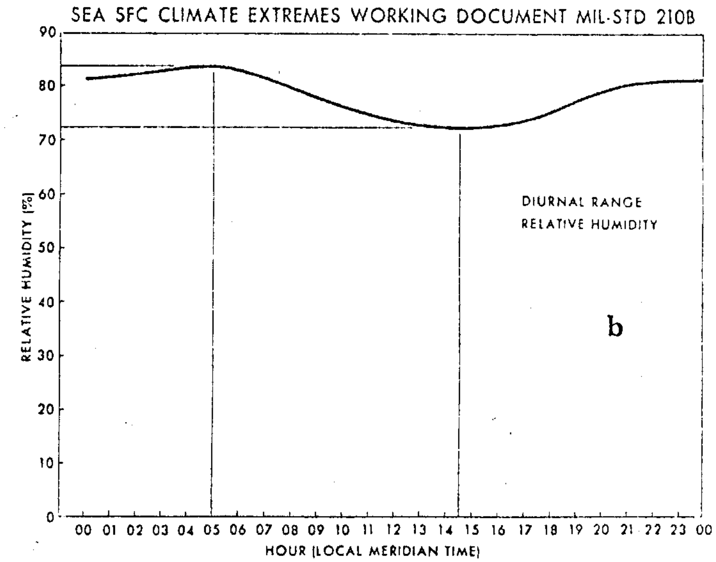


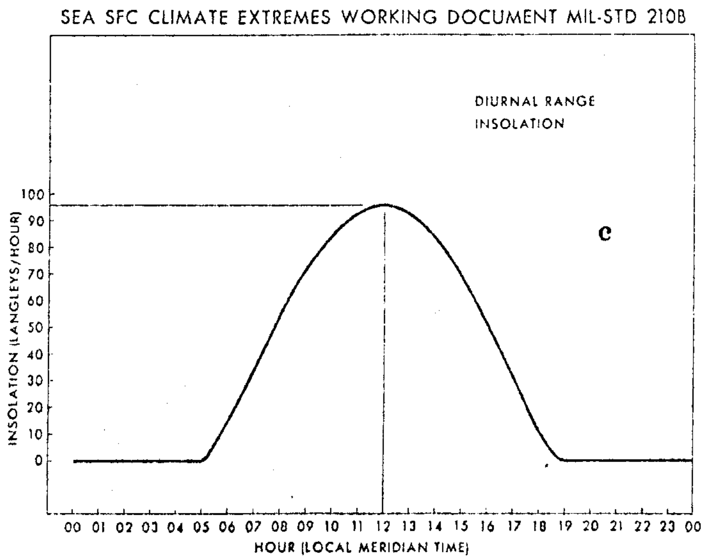
MEAN DIURNAL VARIATION OF ELEMENTS WHEN MAJOR ELEMENT (CURVE a) EQUALS OR EXCEEDS THE 0.01 EMPIRICAL PROBABILITY LEVEL

PROBABILITY	MAX AIR TEMPERATURE
.01 =	118.0° F, 47.8° C
.05 =	114.3° F, 45.7° C
.10 =	113.3° F, 45.2° C
.20 =	109.9° F, 43.3° C

FIGURE 3. PORT MAXIMUM AIR TEMPERATURE



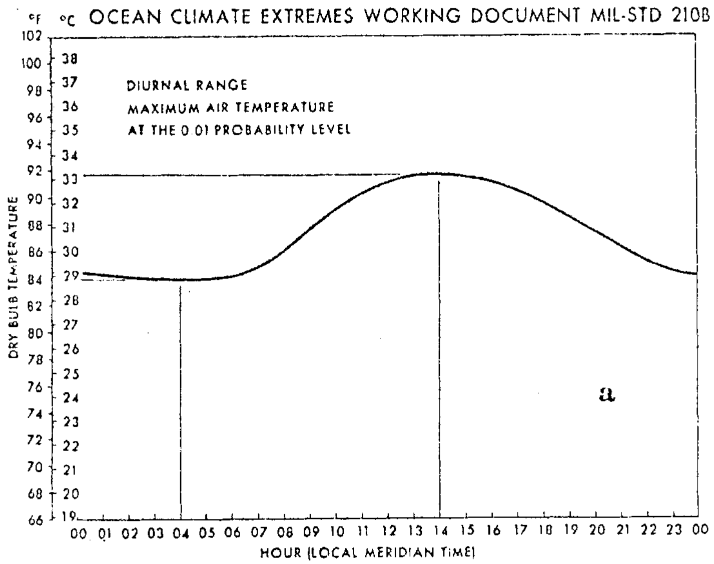


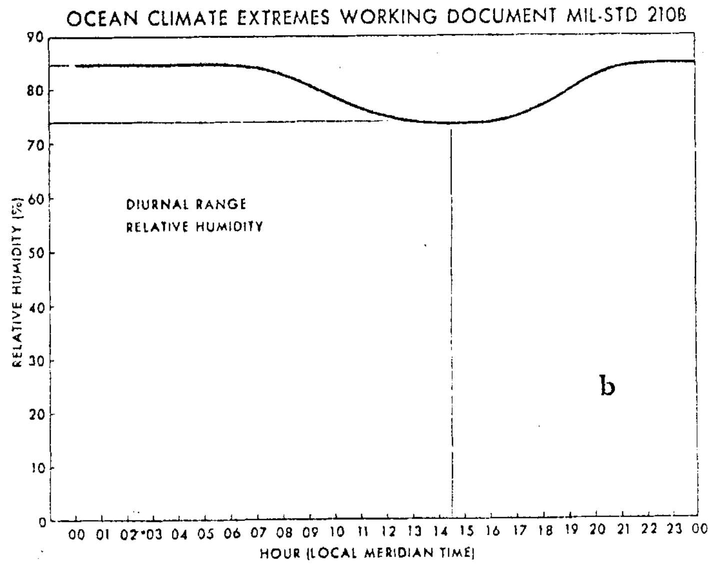


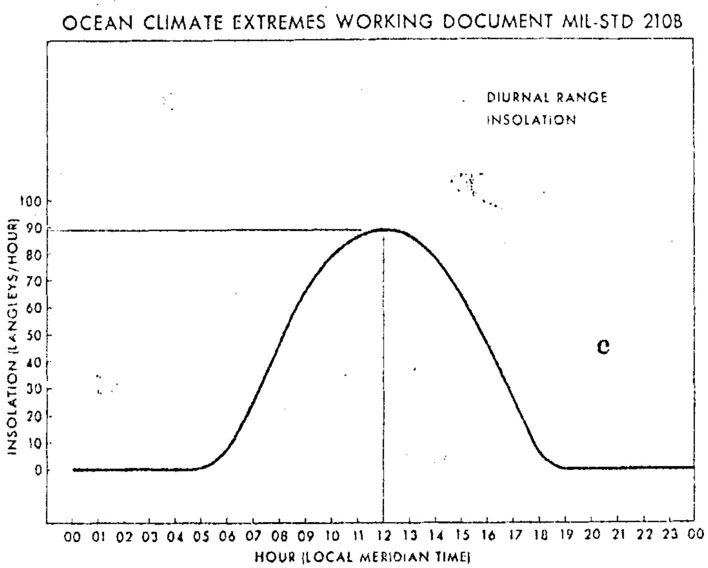
MEAN DIURNAL VARIATION OF ELEMENTS
WHEN MAJOR ELEMENT (CURVE a) EQUALS
OR EXCEEDS THE 0.01 EMPIRICAL
PROBABILITY LEVEL

PROBABILITY	MAX AIR TEMPERATURE
.01 =	99.8° F, 37.7° C
.05 =	97.0° F, 36.1° C
.10 =	95.6° F, 35.3° C
.20 =	93.9° F, 34.4° C

FIGURE 4. SEA SFC MAXIMUM AIR TEMPERATURE



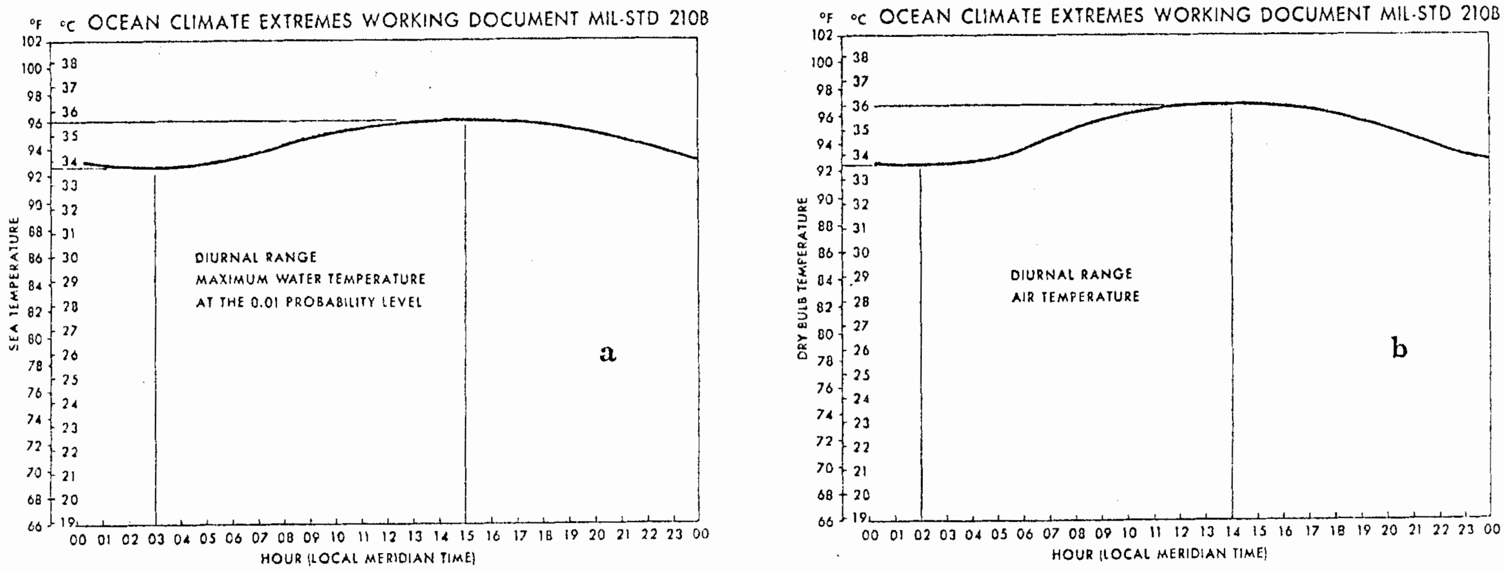


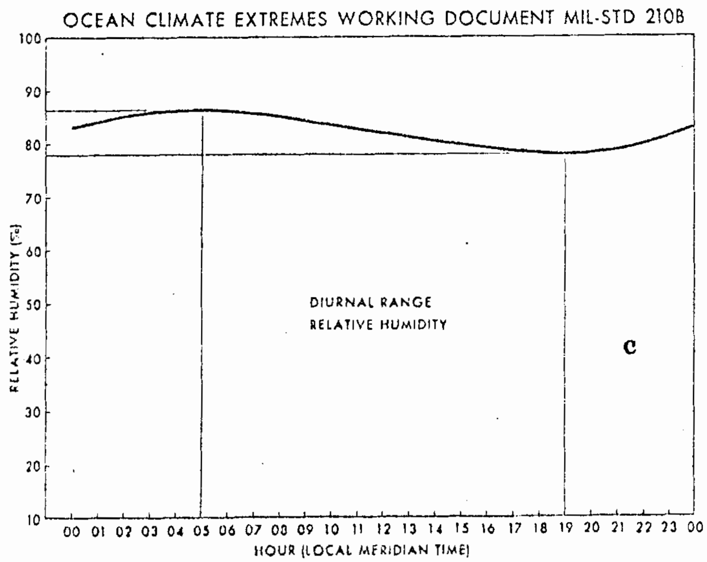


MEAN DIURNAL VARIATION OF ELEMENTS WHEN MAJOR ELEMENT (CURVE a) EQUALS OR EXCEEDS THE 0.01 EMPIRICAL PROBABILITY LEVEL

PROBABILITY	MAX AIR TEMPERATURE
.01 =	91.9° F, 33.3° C
.05 =	88.0° F, 31.1° C
.10 =	86.4° F, 30.2° C
.20 =	84.9° F, 29.4° C

FIGURE 5. OCEAN MAXIMUM AIR TEMPERATURE

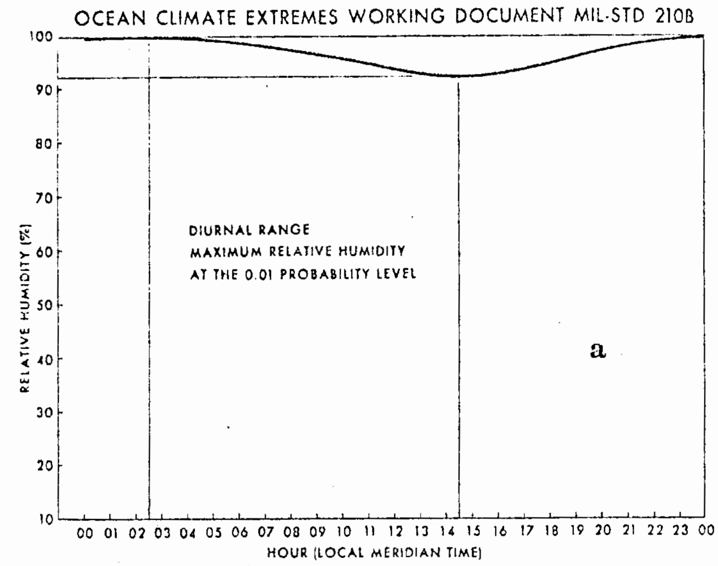


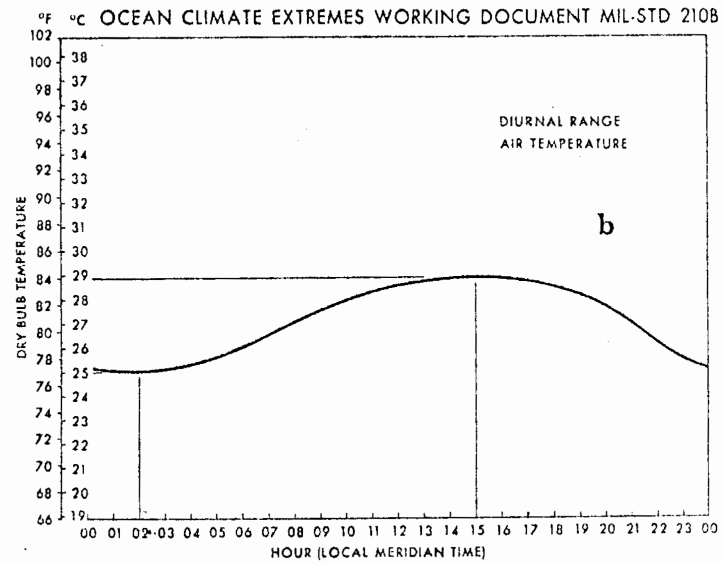


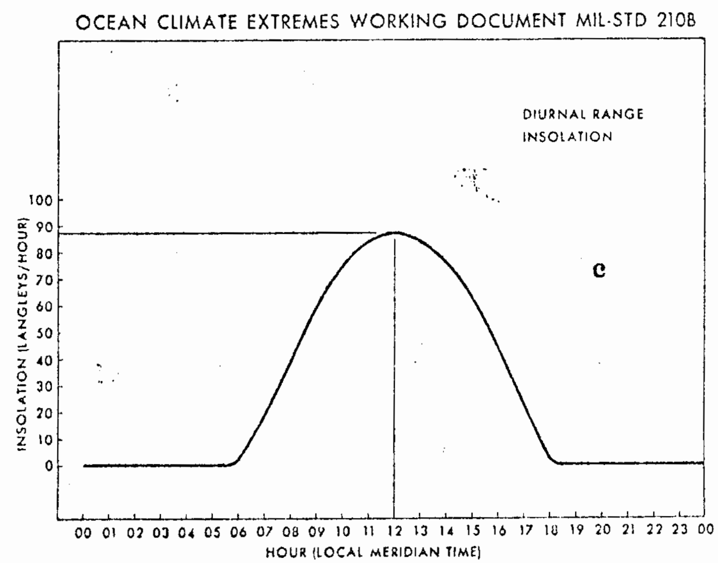
MEAN DIURNAL VARIATION OF ELEMENTS
WHEN MAJOR ELEMENT (CURVE a) EQUALS
OR EXCEEDS THE 0.01 EMPIRICAL
PROBABILITY LEVEL

PROBABILITY	WATER TEMPERATURE
.01	= 96.1° F, 35.6° C
.05	= 95.0° F, 35.0° C
.10	= 93.9° F, 34.4°C
.20	= 93.0° F, 33.9°C

FIGURE 6. OCEAN MAXIMUM SEA TEMPERATURE



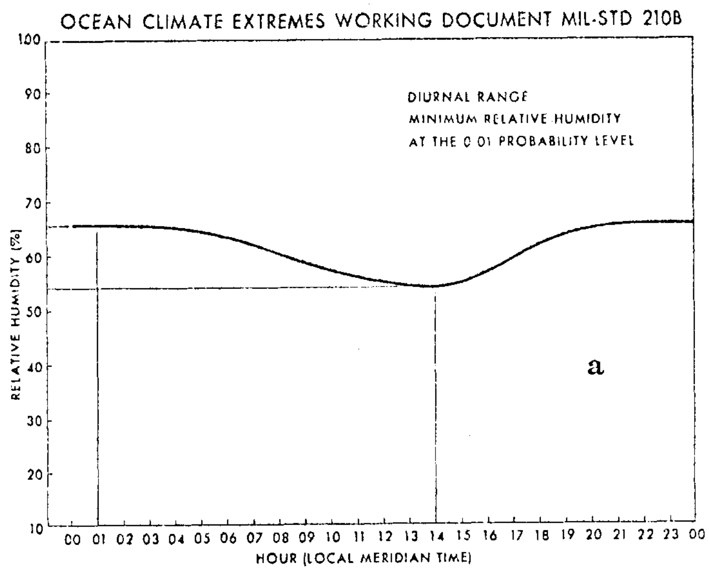


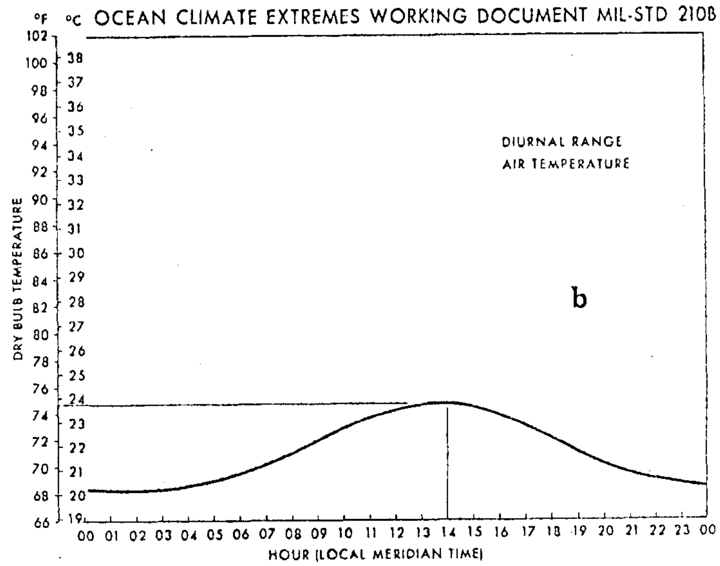


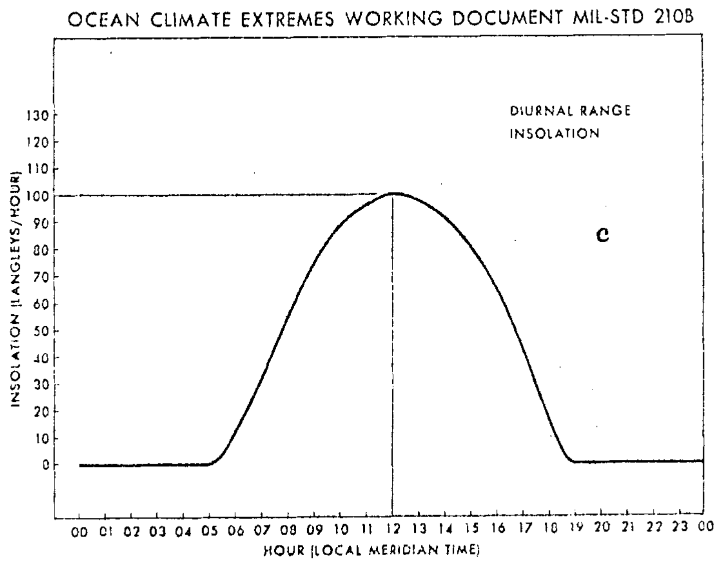
MEAN DIURNAL VARIATION OF ELEMENTS WHEN MAJOR ELEMENT (CURVE a) EQUALS OR EXCEEDS THE 0.01 EMPIRICAL PROBABILITY LEVEL

PROBABILITY	HIGH RELATIVE HUMIDITY
.01	= 100%
.05	= 96%
.10	= 91%
.20	= 84%

FIGURE 7. OCEAN HIGH RELATIVE HUMIDITY



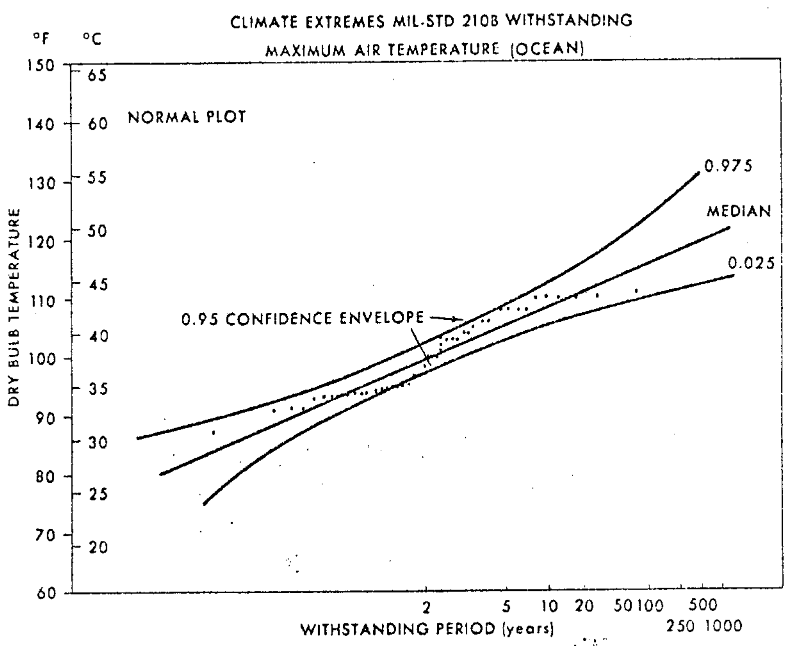




MEAN DIURNAL VARIATION OF ELEMENTS WHEN MAJOR ELEMENT (CURVE a) EQUALS OR EXCEEDS THE 0.01 EMPIRICAL PROBABILITY LEVEL

PROBABILITY	LOW RELATIVE HUMIDITY
.01 =	55%
.05 =	62%
.10 =	67%
.20 =	72%

FIGURE 8. OCEAN LOW RELATIVE HUMIDITY



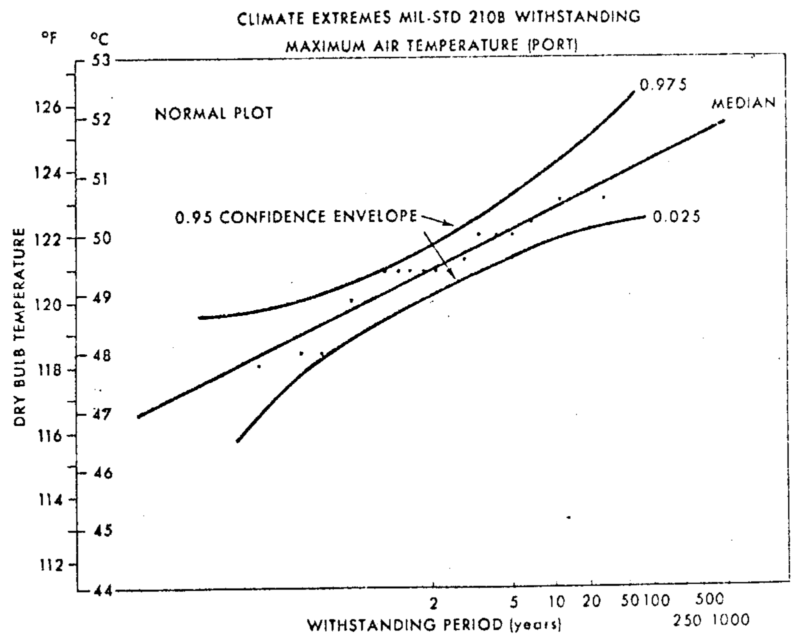


FIGURE 9. MAXIMUM AIR TEMPERATURE - WITHSTANDING

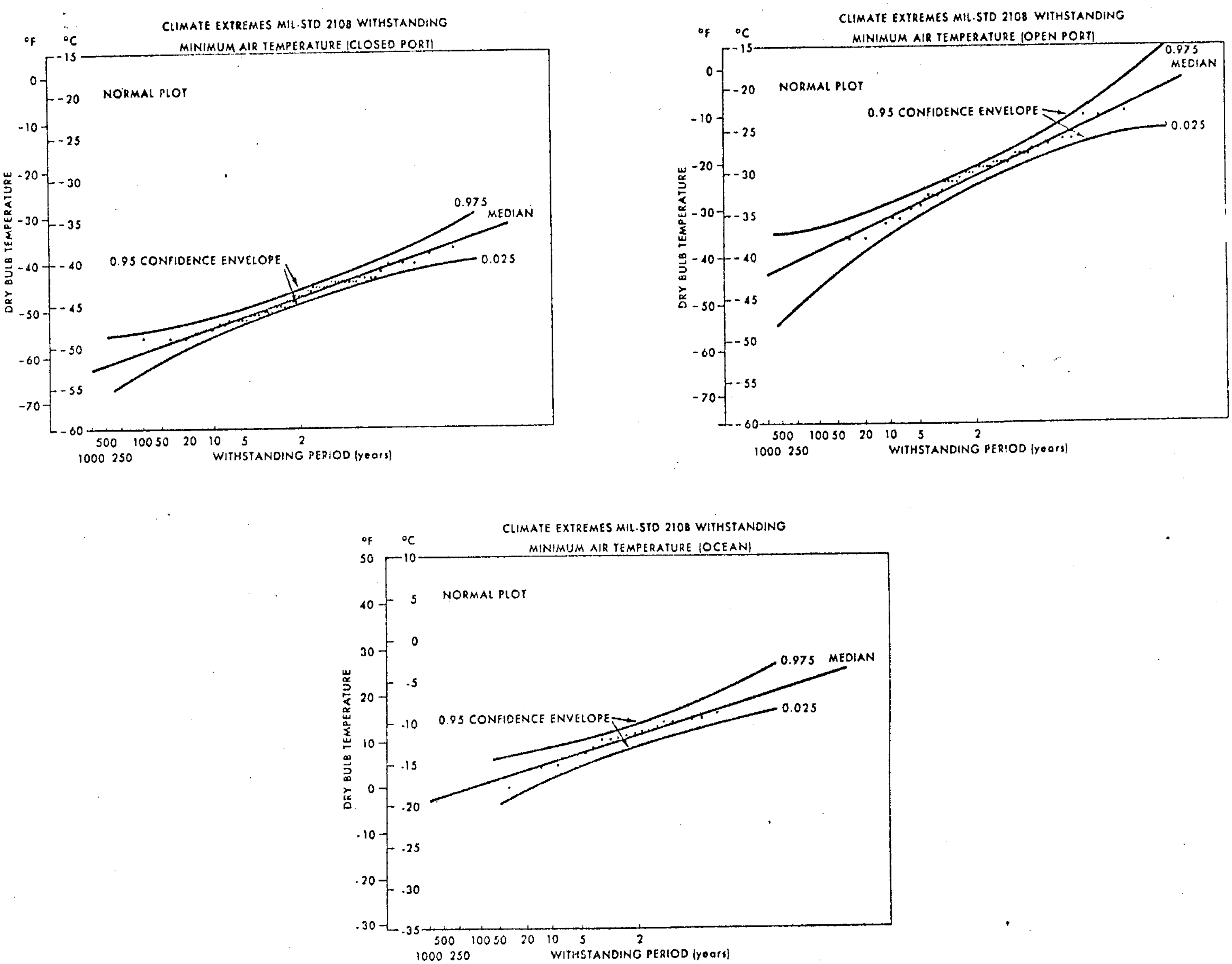


FIGURE 10. MINIMUM AIR TEMPERATURE - WITHSTANDING

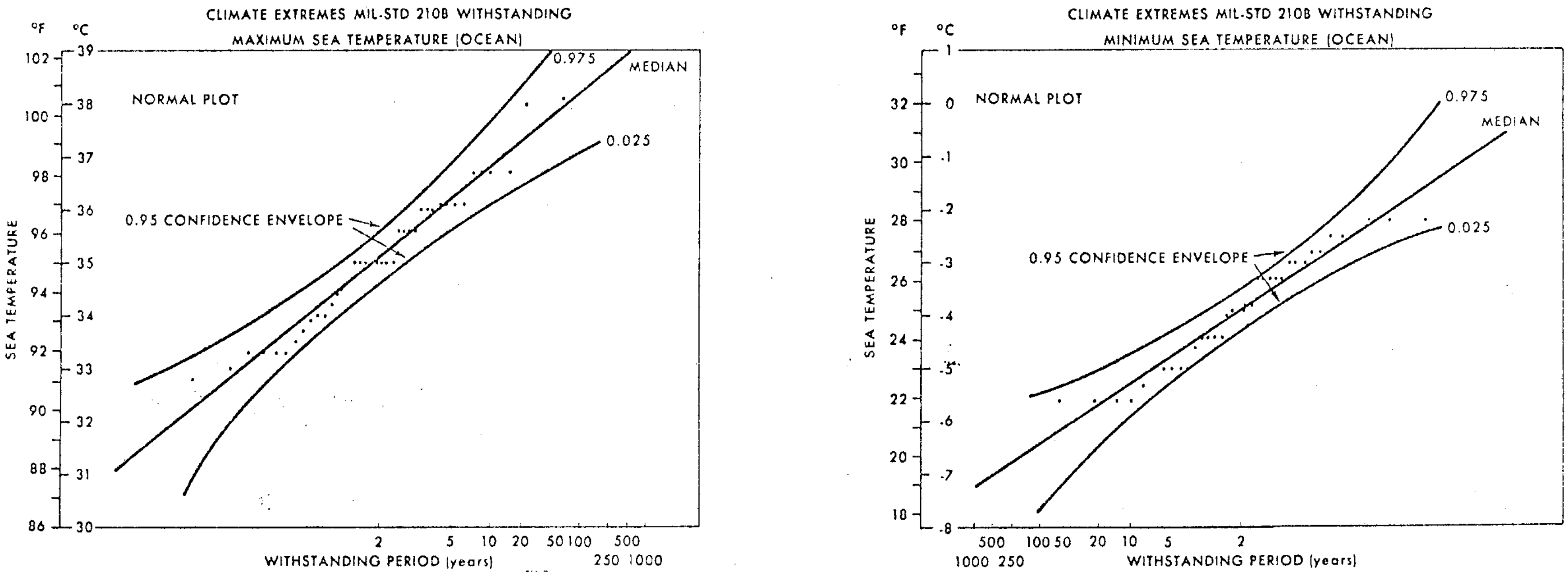
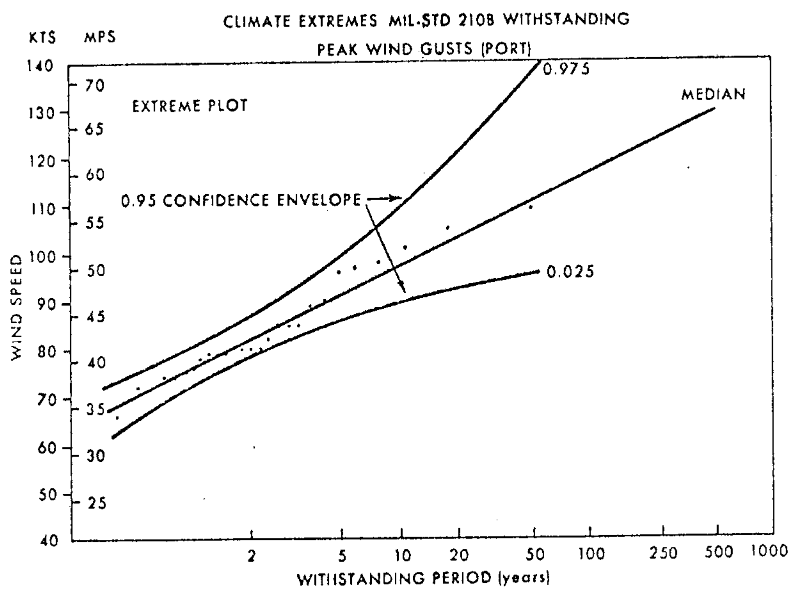


FIGURE 11. SEA TEMPERATURE EXTREMES - WITHSTANDING



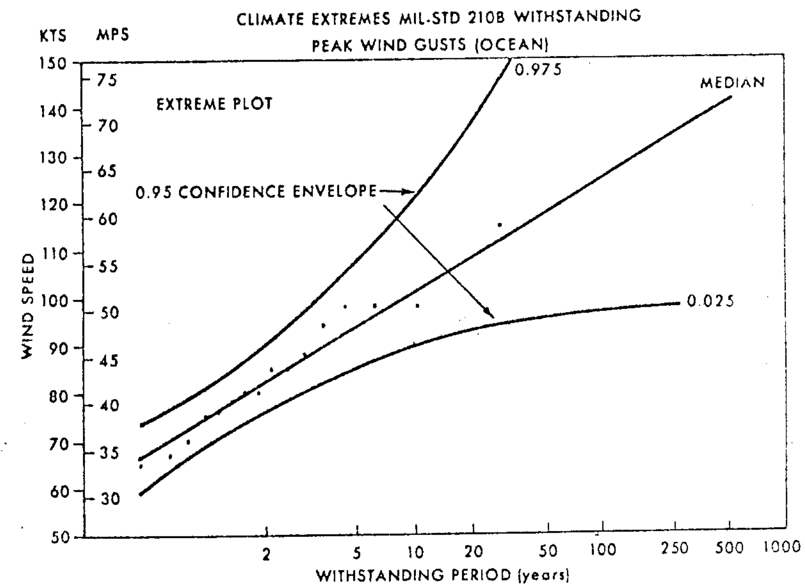


FIGURE 12. MAXIMUM PEAK GUSTS - WITHSTANDING

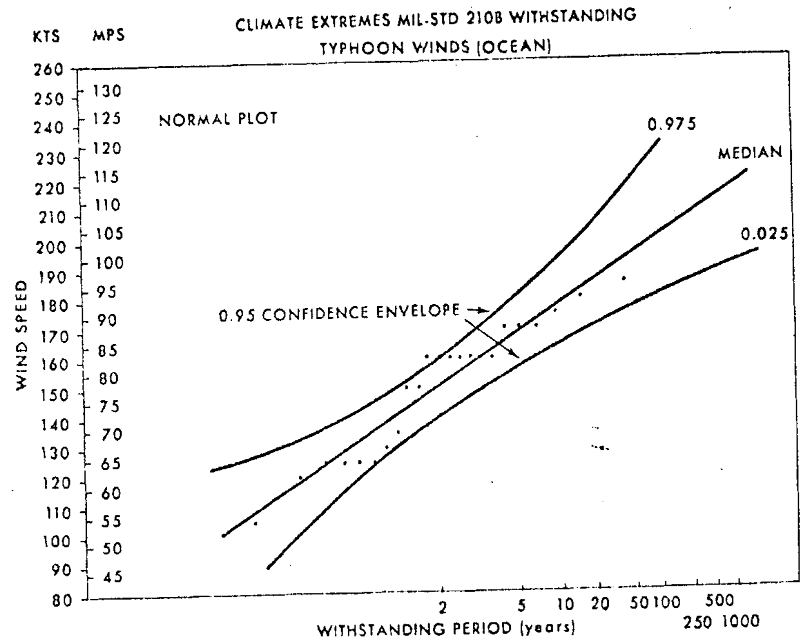


FIGURE 13. MAXIMUM TYPHOON WINDS - WITHSTANDING

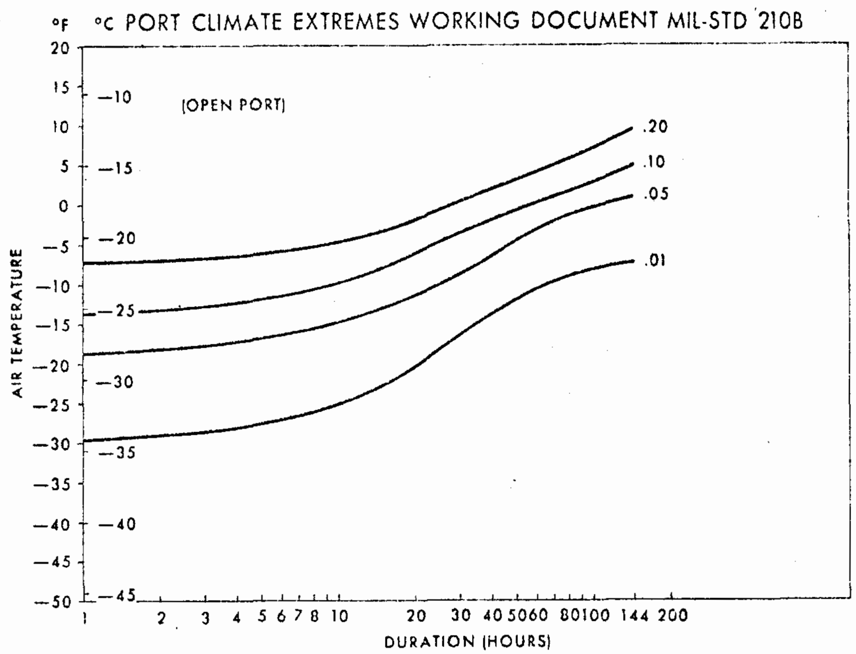


FIGURE 14. PORT MINIMUM AIR TEMPERATURE-DURATION

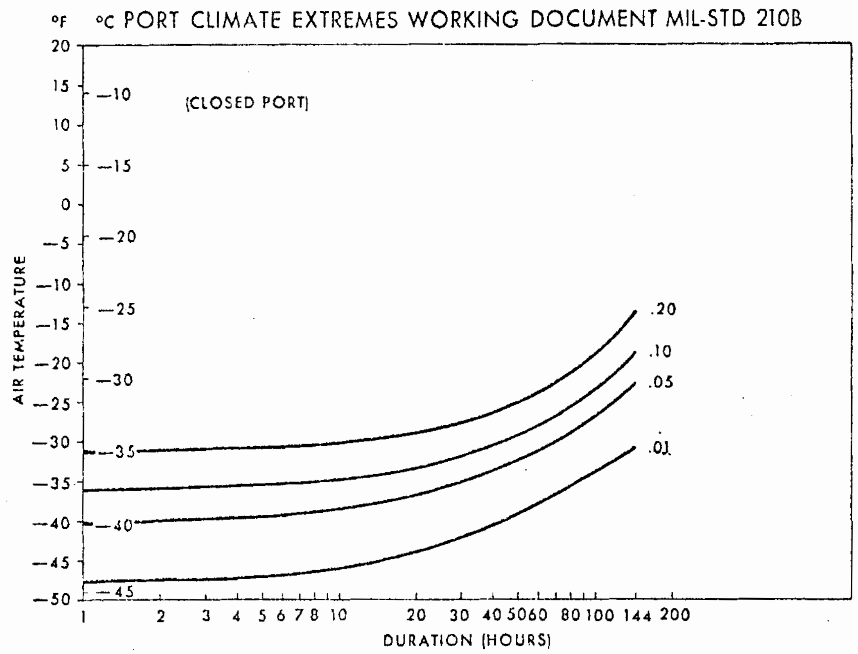


FIGURE 15. PORT MINIMUM AIR TEMPERATURE-DURATION

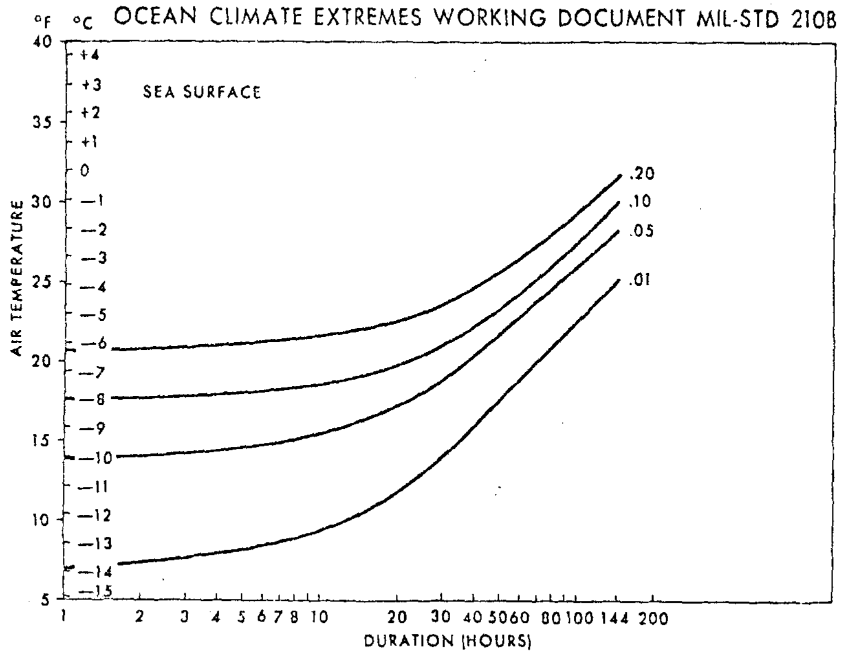


FIGURE 16. OCEAN MINIMUM AIR TEMPERATURE-DURATION

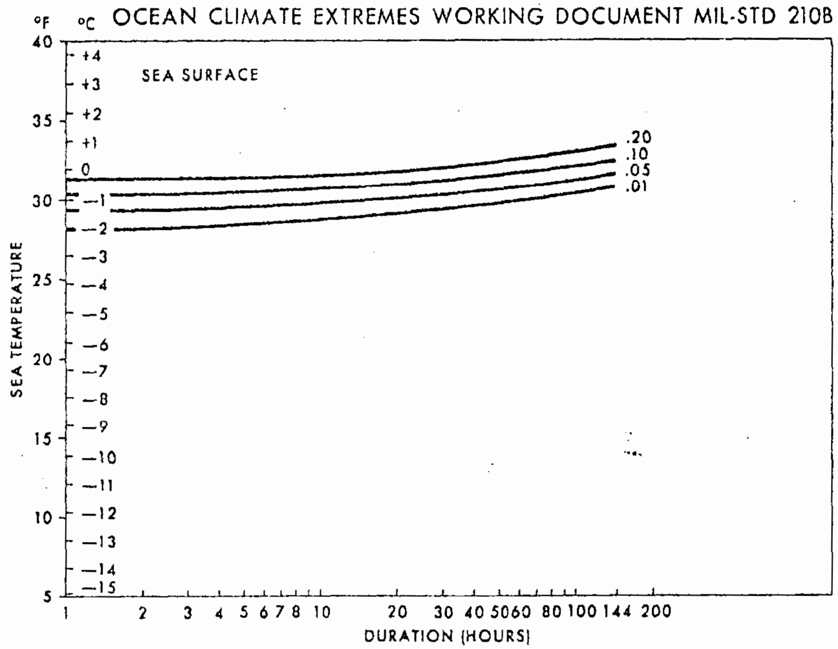


FIGURE 17. OCEAN MINIMUM SEA TEMPERATURE-DURATION

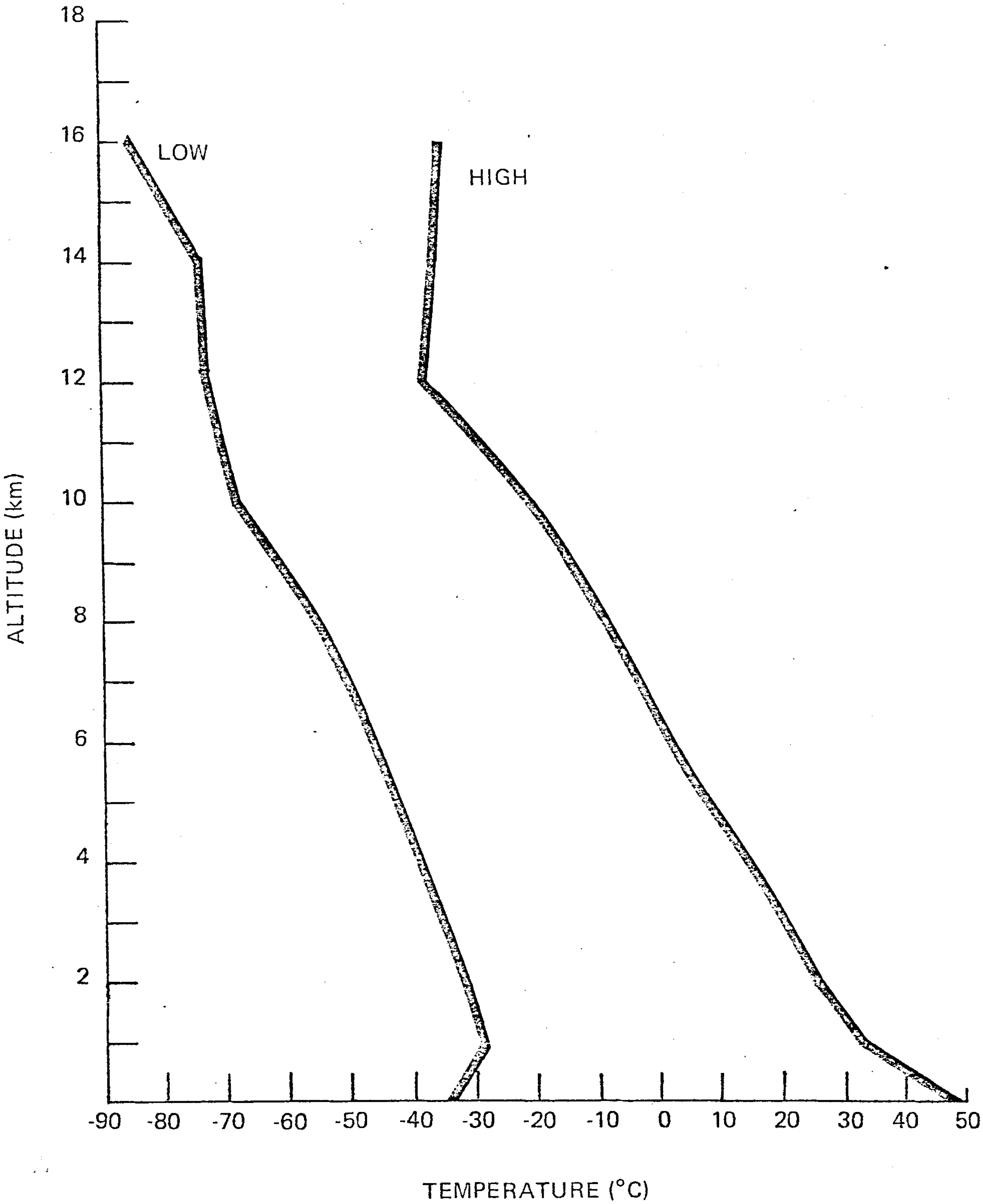


FIGURE 18. EXTREME (1% RISK) TEMPERATURE PROFILE OVER NAVIGABLE WATERS